Effects of Positive versus Negative Yaw Angles on Wind-Turbine Performance: An Application of BEM Theory

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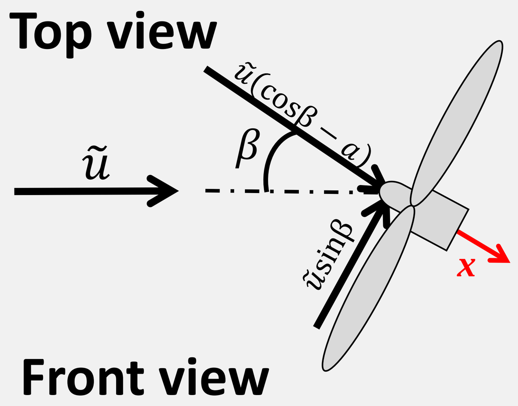
Introduction

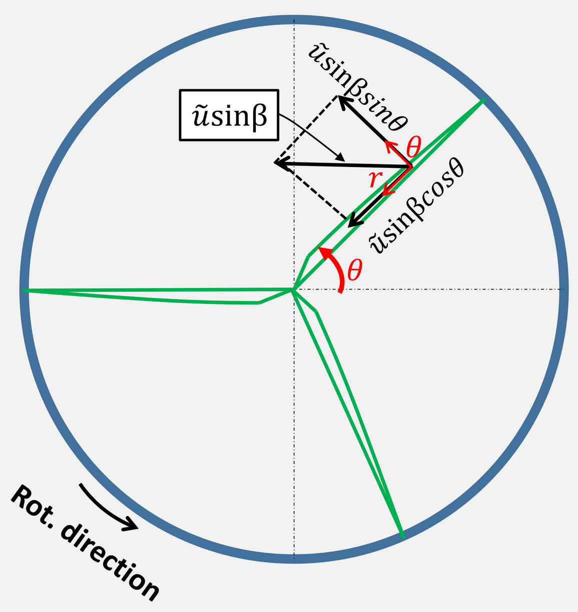
- A turbine can be in yawed conditions in which wind is not perpendicular to the rotor plane.
- Yawed conditions induce unsteady loads on turbine blades which affect the quality of generated power and fatigue life.
- To better understand these effects, the blade element momentum (BEM) theory, which is modified to take into account the unsteadiness of yawed conditions, is used in the present work.
- Special emphasis is placed on the use of BEM to investigate the difference between the effect of **positive** and **negative** yaw angles on the performance of turbines in uniform and boundary-layer flows.

Velocity Diagram

Top view



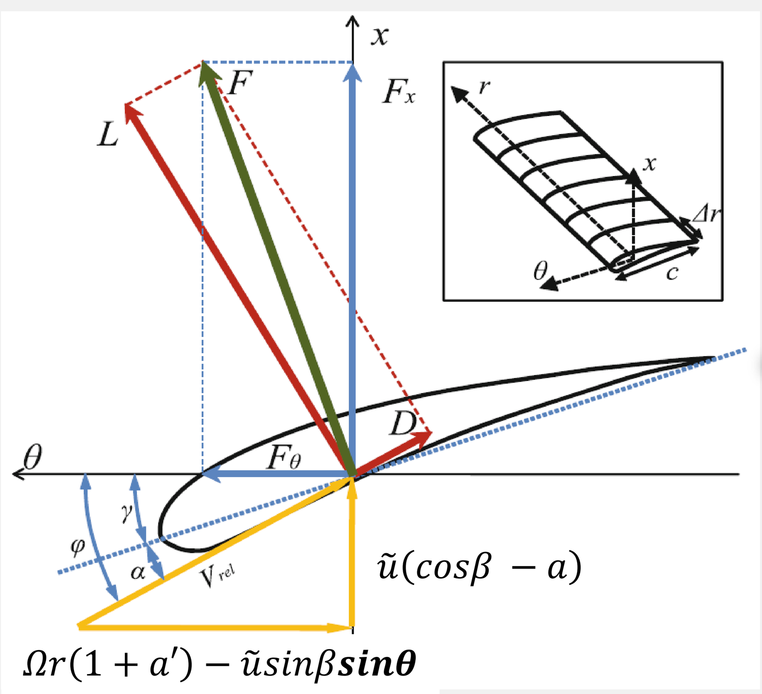
Front view



Method

Blade Element Momentum (BEM) Theory

Blade Element Theory



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Momentum Theory

Glauert's momentum equation

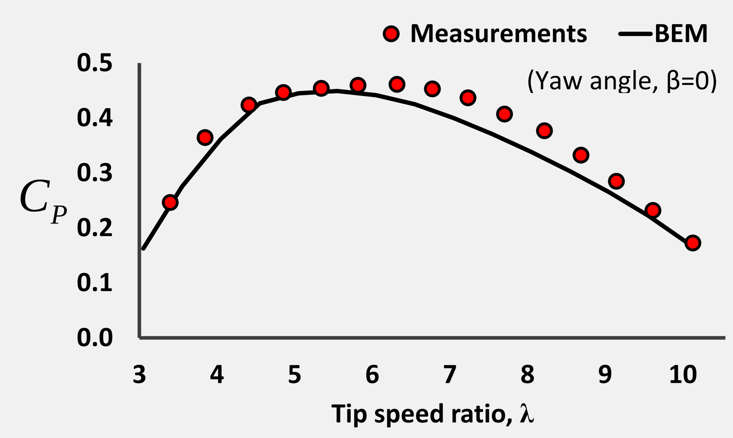
$$C_T = 4a\sqrt{\sin^2\beta + (\cos\beta - a)^2}$$

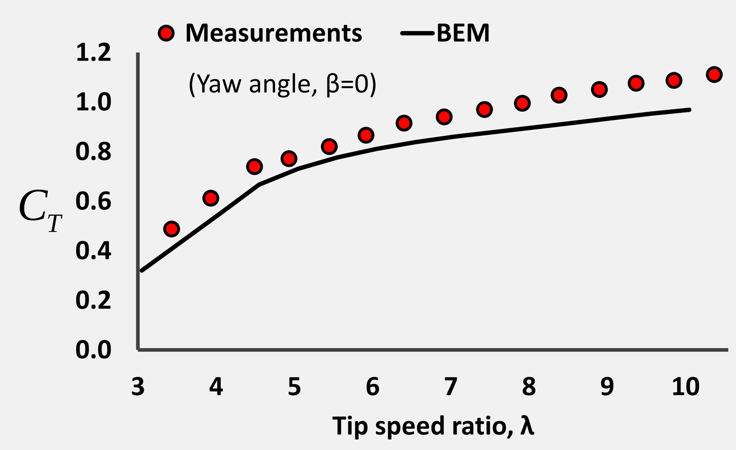
where, $a = \bar{a}\left(1 - K\frac{r}{R}\cos\theta\right)$

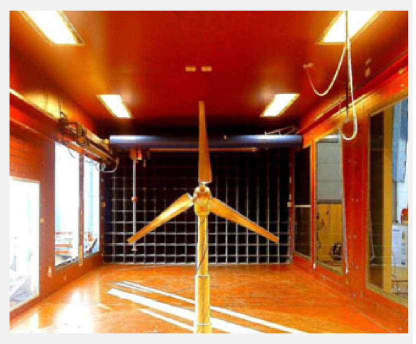
Angular momentum equation

$$C_p = 4a(1-a)^2$$

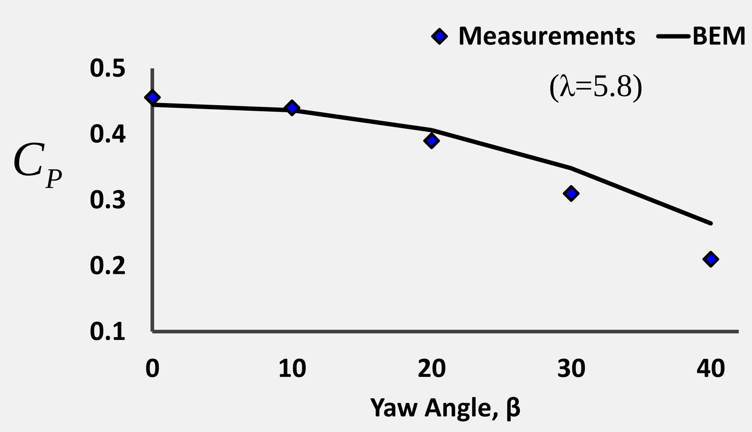
BEM code validation

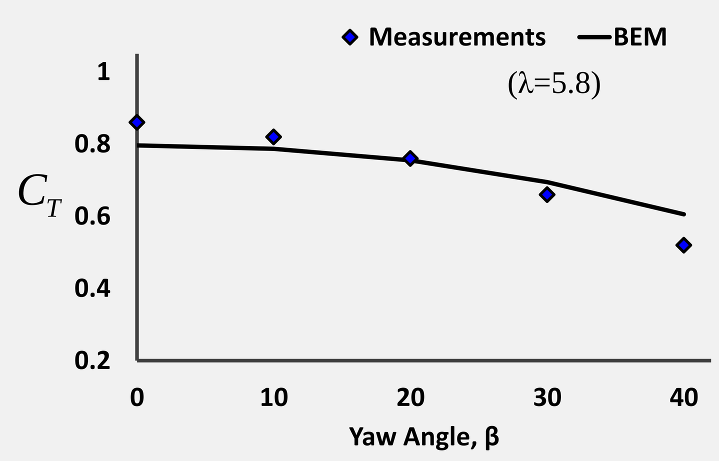




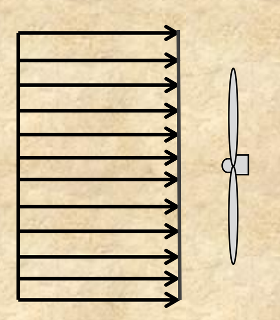
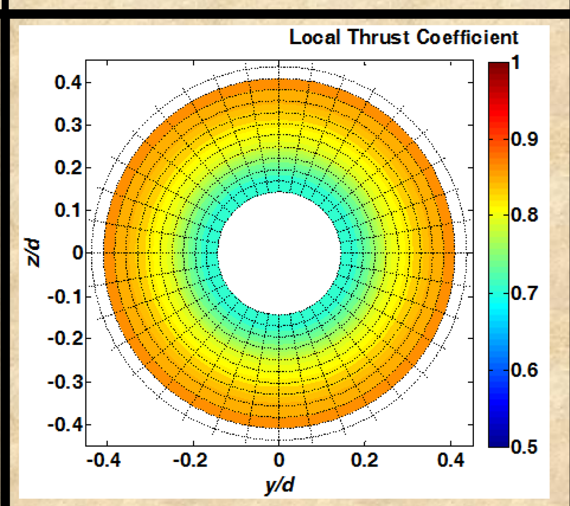
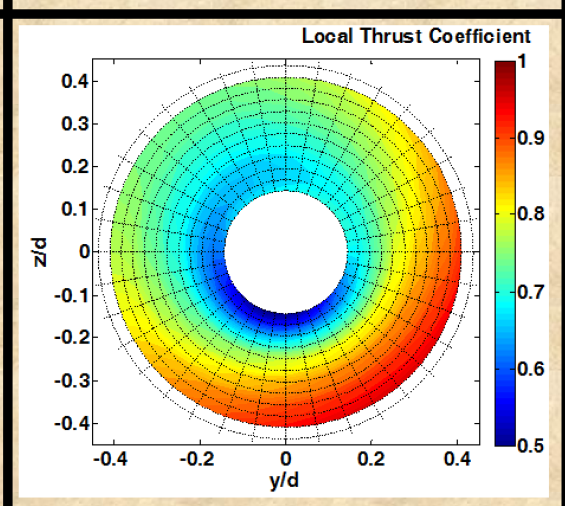
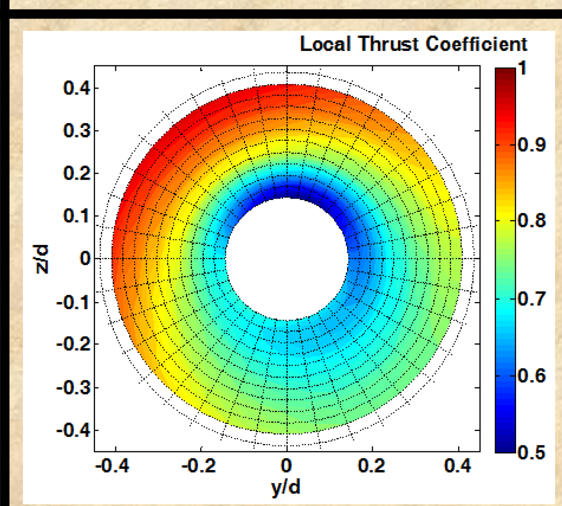
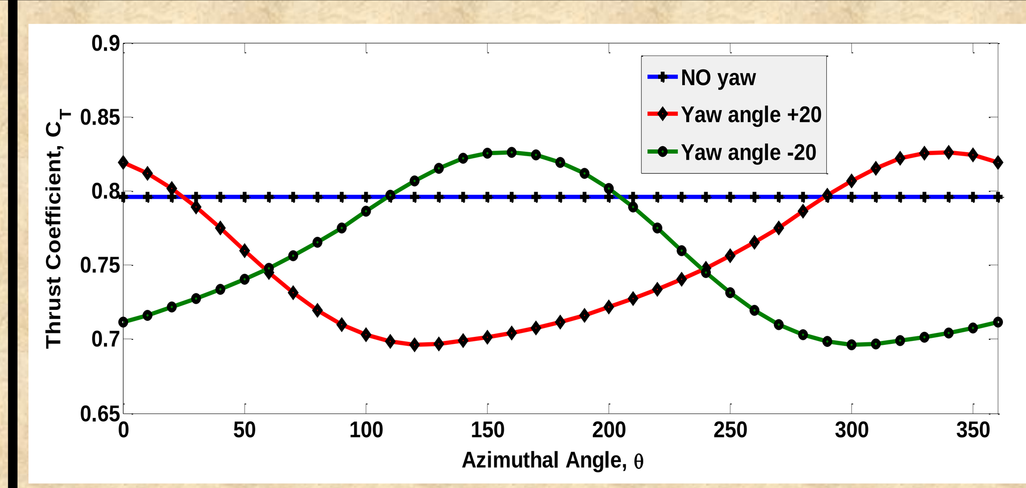
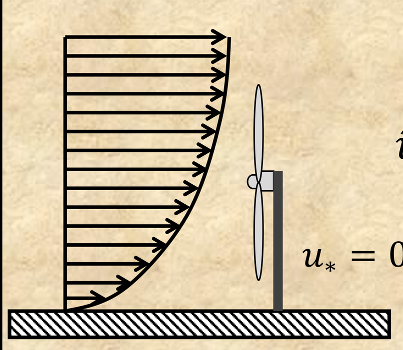
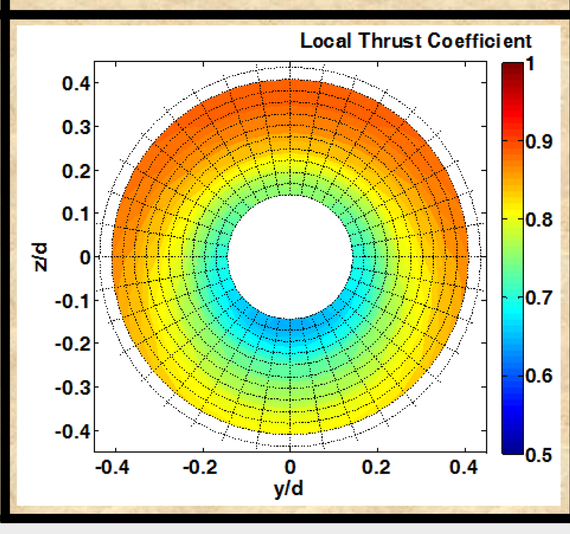
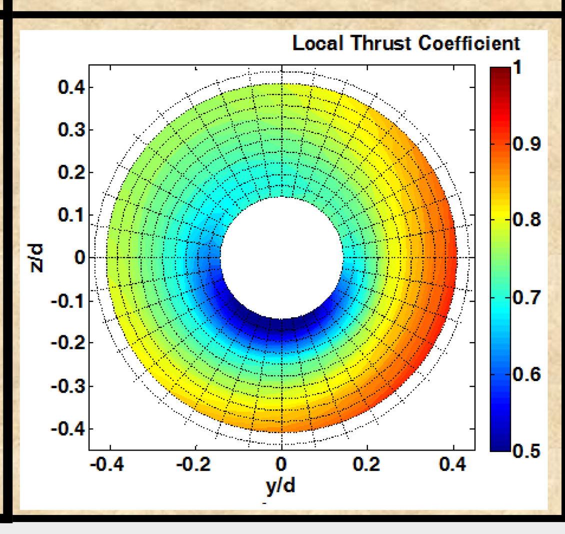
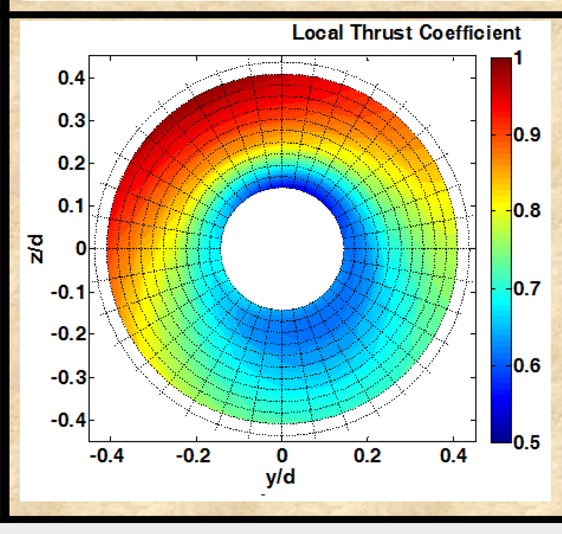
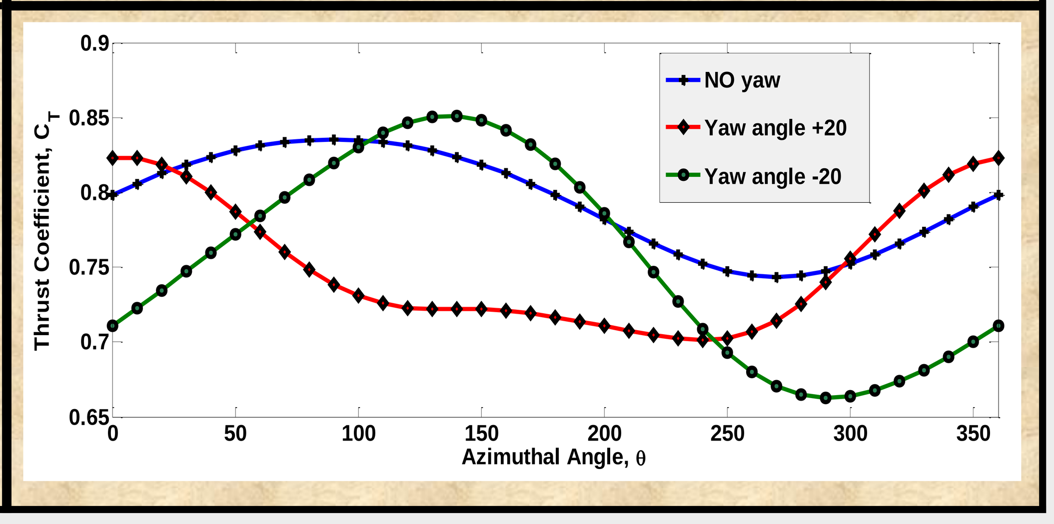


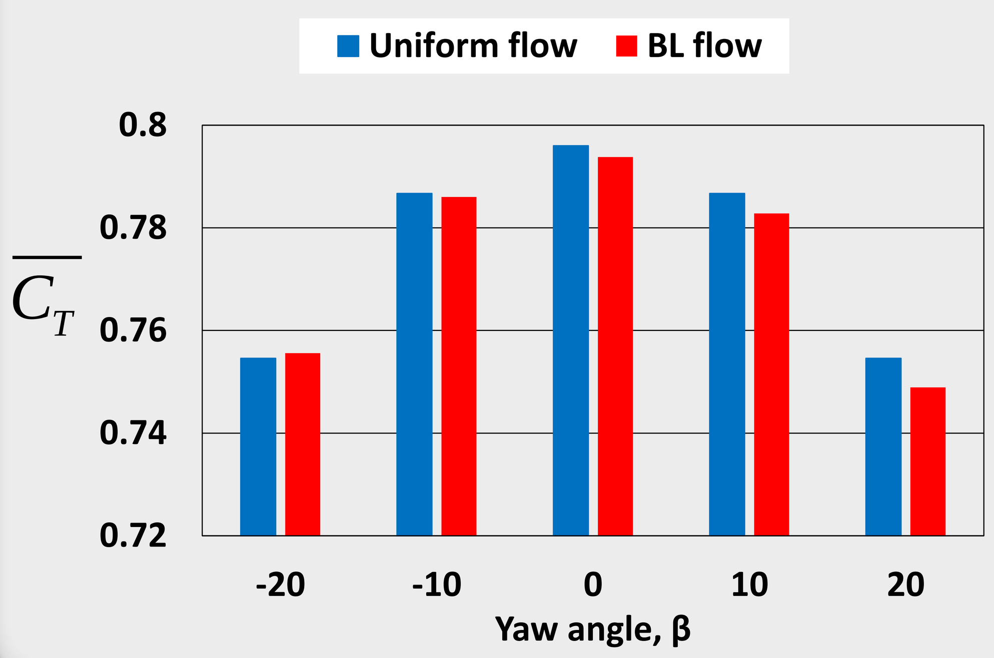
P. Krogstad & M.S. Adaramola (2012)

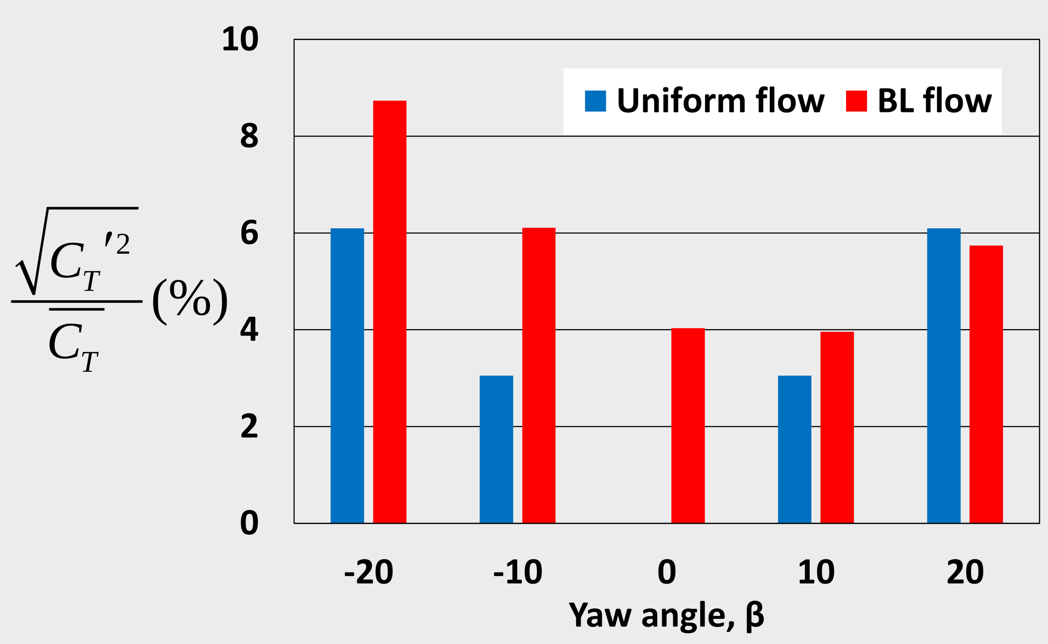




Results

Flow type	Zero Yaw Angle	Yaw Angle, β = +20°	Yaw Angle, β = -20°	Thrust Coefficient vs Azimuthal angle
Uniform Flow  $\tilde{u} = 10\ m/s$				
Boundary-layer Flow  $\tilde{u} = \frac{u_*}{k} ln\left(\frac{z}{z_0}\right)$ $u_* = 0.6\frac{m}{s}, z_0 = 1\ mm$				





Main Conclusions

- In uniform flows, the loads on yawed turbines vary as the blade rotates, but their variations are similar for both positive and negative yaw angles.
- **In boundary-layer flows, the variation of forces acting on blades is NOT the same for positive and negative yaw angles.**
- The **time-averaged** loads acting on yawed turbines are approximately the same for positive and negative yaw angles.